

Grain Sorghum as a Trap Crop for Corn Earworm (Lepidoptera: Noctuidae) in Cotton

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Environ. Entomol. 33(5): 1371–1380 (2004)

ABSTRACT This 2-yr on-farm study was designed to evaluate the ability of grain sorghum, *Sorghum bicolor* (L.) Moench, to serve as a trap crop for the corn earworm, *Helicoverpa zea* (Boddie), by attracting corn earworm females into the sorghum as they emerged from cornfields. Three plots of sorghum trap crops and three equally sized plots of cotton, *Gossypium hirsutum* L., trap crops were planted in a strip between a commercial cornfield and a commercial cotton field. The cotton field adjacent to the trap crop plots was divided into field cotton plots associated with the sorghum trap crop plots and field cotton plots associated with the cotton trap crop plots. Three commercial cotton fields adjacent to corn, but without trap crops, also were sampled. The number of corn earworm eggs per plant and the percentage of plants with corn earworm eggs was higher in the sorghum trap crop plots than in the cotton trap crop plots for both years, demonstrating that corn earworm females preferred to oviposit in the grain sorghum over cotton. A higher percentage of plants with corn earworm eggs was found in cotton in control fields compared with fields with trap crops, indicating that the grain sorghum trap crop was not the source of corn earworm. An economic threshold of 5% corn earworm young (first and second instars) was exceeded more times for cotton in control fields compared with cotton in fields with trap crops. Thus, for two seasons the grain sorghum trap crops helped reduce the need for insecticide applications for this pest. Percentage of parasitization by the egg parasitoid *Trichogramma pretiosum* Riley and the number per plant of the predator *Orius insidiosus* (Say) were higher in the sorghum trap crop plots than the cotton plots. However, the grain sorghum trap crop plots were not sinks for these natural enemies. We conclude that grain sorghum could serve as an effective trap crop for corn earworm in cotton.

KEY WORDS grain sorghum, *Helicoverpa zea*, corn earworm, trap crop, cotton

THE CORN EARWORM, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), complex, along with southern green stink bug, *Nezara viridula* (L.), and brown stink bug, *Euschistus servus* (Say), are the most common targets of insecticide applications for cotton, *Gossypium hirsutum* L., production in boll weevil-eradicated states (Williams 2003). *Bacillus thuringiensis* (Bt) cotton has not always provided satisfactory control of corn earworm due to temporal and spatial variability in the expression of the CryIA (c) among plant parts (Adamczyk et al. 2001). Thus, since the advent of Bt cotton, corn earworm has become the predominant pest species of this heliothine complex, and stink bugs have emerged as pests of increasing importance. In addition, important natural enemies of corn earworm, including the predator *Orius insidiosus* (Say) and the parasitoid *Trichogramma pretiosum* Riley, in corn, *Zea mays* L.; grain sorghum, *Sorghum bicolor* (L.) Moench; and cotton (Quaintance and Brues 1905, Barber 1936, Steward et al. 1990) are

highly susceptible to many of the most commonly used insecticides for control of cotton pests (Tillman 1995, Tillman and Scott 1997, Tillman and Mulrooney 2000). We need to move toward a biologically based integration pest management strategy with reduced inputs for a solution to corn earworm problem in cotton. The cultural practice of trap cropping can be one of the most environmentally friendly ways to manage crop pests.

Trap crop strategies have proven themselves highly effective on tough pests in cropping systems in recent years and offer the potential to minimize or eliminate the use of insecticides and preserve natural enemies that control pests, while maintaining or increasing crop quality and yield (Hokkanen 1991). The idea is simple: intercept the insect with a plant that is more attractive to the pest than the main crop. Thus, a strong host plant preference by a pest for the plant species used in the trap crop is the main requirement for the success of this pest management strategy. For example, *Lygus hesperus* Knight prefers lushly growing alfalfa, *Medicago sativa* L., over cotton, and strips of this crop interspersed in cotton fields virtually eliminate

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the need to spray the main crop for *Lygus* bug control (Stern et al. 1969, Sevacherian and Stern 1974). *Helicoverpa* spp. attack corn and grain sorghum preferentially over most other crop hosts (Neunzig 1969, Graham et al. 1972, Roome 1975, Stinner et al. 1977). Therefore, in 1999, a small plot test was conducted on an experimental farm to examine ovipositional response of corn earworm females to grain sorghum and cotton. The results from the tests indicated that corn earworm females were highly attracted to grain sorghum panicles preferring this plant species to cotton (P.G.T., unpublished data). Thus, we hypothesized that grain sorghum would be an effective trap crop for this pest in cotton.

Dispersal behavior of pests can contribute to the success of trap cropping as a pest management strategy. For example, a strip of early-planted potato, *Solanum tuberosum* L., placed between the previous season's potato field and the new potato field served as a trap crop and sink for Colorado potato beetles, *Lepidotarsa decemlineata* (Say), as they dispersed from the old fields in which they had overwintered (R. T. Roush, personal communication). The phenology of corn earworm is closely bound to crop phenology and seasonal succession of host plants, making trap cropping a suitable strategy for control for this pest. Many growers include crop rotation as a normal cultural practice in crop production. The landscape can consist of wooded areas, weedy field edges, fence rows, grassy meadows, and a variety of agricultural crops, including corn, cotton, and peanuts, *Arachis hypogaea* L. Thus, farming practices can create a unique temporal and spatial pattern of crop phenology. Corn earworm exhibits an early-season population buildup on corn and a mid-to-late season movement to flowering and squaring cotton as corn dries out and becomes an unsuitable host (Quaintance and Brues 1905, Snow 1964, Ridgway 1969). Preliminary tests using rubidium marking have provided further evidence that corn earworm from corn adjacent to cotton move into the cotton (P.G.T., unpublished data). Corn earworm can occur on sorghum panicles in southeastern Georgia from late June through September, the period during which this pest can disperse from corn into cotton (Barber 1937). *Helicoverpa* species exhibit a strong ovipositional preference for the flowering stage of their hosts (Quaintance and Brues 1905, Parsons 1940, Roome 1975), and corn earworm are equally attracted to all stages of flowering in sorghum panicles (Kring et al. 1989). Therefore, the addition of grain sorghum at this attractive stage to corn earworm at the right time and place in this landscape could lead to a concentration of corn earworm in the grain sorghum, protecting cotton, the cash crop.

Our 2-yr research project was conducted to evaluate the ability of grain sorghum plots along the edge of a cotton field adjacent to corn to serve as trap crops for corn earworm in the cotton. This research was conducted on-farm to provide a real-world evaluation of the effectiveness of this management strategy that has the potential to improve sustainability of farm systems by reducing off-farm inputs.

Materials and Methods

The ability of grain sorghum to serve as a trap crop for corn earworm in cotton was investigated in commercial cotton fields on three separate farms owned and operated by producers in Irwin County, Georgia, in 2001 and 2002. An evaluation of the concept of using grain sorghum as a trap crop for corn earworm is presented in this report. Attractiveness of corn earworm females to developmental stages of grain sorghum panicles and population dynamics of insects over time are beyond the scope of this article and will be reported in subsequent articles.

Crop Management. Grain sorghum was planted at a rate of 25,500 seeds per hectare by using a two-row John Deere (Deere & Co., Moline, IL) planter. A numerically lower number of corn earworm larvae was recovered from an open-panicle sorghum variety, DeKalb E57, than from a fairly compact-panicle variety, ATx2755 \times RTx2767 (Teetes et al. 1992). We used the DeKalb E57 sorghum variety for this research instead of a compact-panicle to decrease the possibility that sorghum would become a source of this pest in cotton. Timing of planting grain sorghum was scheduled to coordinate flowering of this plant with the period of time corn earworm would be dispersing from corn. This variety of sorghum begins flowering 57–60 d after planting and is attractive to corn earworm females for \approx 15 d in southern Georgia (P.G.T., unpublished data). In 2001, the first two planting dates for grain sorghum were 30 April and 14 May. For the third planting date, grain sorghum was planted on 29 May, but it had to be replanted on 7 June because the seedlings died due to drought. In 2002, the three planting dates were 13 May, 23 May, and 3 June. Planting dates were later in 2002 to provide attractive panicles by the first and second week of July when corn earworm females began dispersing from corn in 2001 (P.G.T., unpublished data). Cotton varieties and planting dates were chosen by the producer. In 2001 Delta Pine 5690 Roundup Ready was planted on 8 May. In 2002, Delta Pine 5690 Roundup Ready was planted from 10 May through 21 May. For both years, number of plants was counted in transects of 0.9 m of row (Willers et al. 1992) to determine plant stand densities for sorghum and cotton. All the commercial cotton fields ranged from 8 to 10 ha, and all commercial cornfields associated with these cotton fields ranged from 8 to 12 ha.

Insect Sampling. In both grain sorghum and cotton, corn earworm eggs and larvae were monitored along with *O. insidiosus* nymphs and adults. In cotton, whole plant sampling was used to sample insects weekly before corn earworm females laid eggs in cotton and 3–4 d thereafter. All corn earworm eggs and larvae found on cotton plants during sampling were collected, placed individually in cups containing a bean diet for lepidopteran larvae (Perkins et al. 1973), and transported to the laboratory. Because corn earworm eggs were present in grain sorghum panicles throughout the growing season of this crop, insects were monitored every 3–4 d throughout the development of this

Location with Sorghum and Cotton Trap Crops

[illegible]

R = Replicate; three per species of trap crop.

PD = planting date (three planting dates each with 4 rows in sorghum trap crop plots and one planting date with 12 rows in cotton trap crop plots; rows are horizontal to corn and cotton field).

B = Cotton buffer (9 m) planted between adjacent trap crop and field cotton plots.

S = 15 m section or length of row; three for each trap crop plot and cotton field plot; four in control.

In the cotton field, each block refers to a 15×15 m area in which a random whole plant sample was obtained. The number refers to the greatest distance (m) in the block away from the trap crop so that $15 = 1-15$ m away from trap crop.

Location without Sorghum and Cotton Trap Crops

Control Cotton Field	Corn Field			
	S1	S2	S3	S4
	15	15	15	15
	30	30	30	30
	45	45	45	45
	60	60	60	60
	90	90	90	90
	120	120	120	120
	150	150	150	150
	180	180	180	180

Fig. 1. Experimental plot design for cotton field with trap crops and cotton field without trap crops (not to scale).

plant species. To sample insects in the grain sorghum trap crop plots, panicles were cut, placed in paper bags that were stapled closed, transported to the laboratory, and stored at 15°C. Sorghum panicle development stages have been categorized by Vanderlip (1972) as half-bloom (flowering has progressed halfway down the panicle), soft dough, and hard dough (mature). Panicles were cut throughout the development of the sorghum panicles, from the time panicles were fully exerted from the flag-leaf sheath thorough 2 wk into the hard dough stage.

A sampling design was devised to evaluate the ability of grain sorghum to attract corn earworm females as they dispersed from cornfields into adjacent cotton fields (Deming 1950, Box et al. 1978). For both years of the test, three plots, 45 m in length by 11 m (12 rows) in depth, of sorghum (sorghum trap crop plots) and three equally sized plots of cotton (cotton trap crop plots) were planted in a strip between a commercial cornfield and a commercial cotton field in a randomized complete block (RBC) design (two treatments \times three replicates) (Fig. 1). Rows in the trap crop plots were planted horizontal to the corn and cotton fields and abutted the cornfield on one side and the cotton field on the other side (Fig. 1). Sorghum was planted on three different planting dates (see above) within each sorghum trap crop plot to ensure that flowering panicles that were attractive to corn earworm were available during the period that corn earworm females were dispersing from corn (Fig. 1).

For each planting date, sorghum was planted in four rows (four rows \times three planting dates = 12 rows) with the first planting date placed adjacent to the cornfield (Fig. 1). All 12 rows of cotton in the three cotton trap crops were planted on the same date as field cotton. Regardless of treatment, each trap crop plot was subdivided into three 15-m sections (length of row) (Fig. 1). In sorghum in 2001, an insect sample consisted of panicles from all plants in 0.15 m of row. Three random samples were obtained per 15-m section of row per planting date (nine samples per row, 36 samples per planting date). In 2002, panicles from three plants randomly were obtained per 15-m section of row (nine plants per row, 36 plants per planting date). For both years, all rows with flowering panicles were sampled. In cotton for both years of the study, six plants per section randomly were sampled in each cotton trap crop plot (18 plants per plot). The sorghum trap crop plot and the cotton trap crop plot were each an experimental unit with subsampling occurring in each experimental unit. Regarding collected data, each RCB was a split, split plot in space (sampling location) and time (sampling date).

The cotton field adjacent to the trap crop plots was divided into six cotton field plots, 45 m in length \times 180 m in depth (Fig. 1). Field cotton plots associated with the sorghum trap crop plots and field cotton plots associated with the cotton trap crop plots were arranged in the same RCB design (two treatments \times three replicates) as described previously for the trap

crop plots (Fig. 1). Each field cotton plot also was subdivided into three 15-m sections (Fig. 1). The field cotton plots were further subdivided in 15 by 15-m blocks representing distance away (1–15, 16–30, 31–45, 46–60, 61–90, 91–120, 121–150, and 151–180 m) from the trap crop plots (Fig. 1). A single plant randomly was sampled in each block represented by a number in the field cotton plot in Fig. 1 (18 plants per field cotton plot). The field cotton plot associated with the sorghum trap crop plot and the field cotton plot associated with the cotton trap crop plot each were an experimental unit with subsampling occurring in each experimental unit. Regarding collected data, each RCB was a split, split plot in space (sampling location) and time (sampling date). No insect samples were obtained from the cotton buffers (9 m) planted between adjacent trap crop plots and field cotton plots (Fig. 1). This arrangement of trap crop plots and field cotton plots was repeated in three commercial corn-cotton field locations on separate farms.

On three separate farms, three commercial cotton fields with no trap crops, but adjacent to corn, also were sampled. It was necessary to place the control cotton fields far away from the sorghum trap crop plots so as not to experience any residual effect due to the attractiveness of corn earworm to sorghum. The center of the control cotton field was divided in four 15-m sections, which were further divided into 15 by 15-m blocks representing distance away (1–15, 16–30, 31–45, 46–60, 61–90, 91–120, 121–150, and 151–180 m) from the cornfield (Fig. 1). A single plant randomly was sampled in each block (32 plants per control cotton field) (Fig. 1). Each cotton control field was an experimental unit with subsampling occurring in each experimental unit.

In the laboratory, all insects were removed from a sorghum panicle within 24 h of field collection by rubbing fingers through the panicle up and down its length while gently twirling it. For each year of the test, examination of 100 random sorghum panicles under a dissecting microscope after using this removal technique revealed that the technique was excellent for collecting 99–100% of the corn earworm eggs and larvae and *O. insidiosus* from the panicles. This sampling technique was similar to the “beat-bucket” technique used by Merchant (1989), except our technique was somewhat more efficient than the earlier method because 78–98% of corn earworm larvae were captured by that method. Our sampling technique allowed us to sample the whole panicle more easily than sampling all or a portion of it under a dissecting microscope, and Kring et al. (1989) reported that corn earworm females do not have an ovipositional preference for any portion of the grain sorghum panicle. As nymphs and adults of *O. insidiosus* dropped from the panicles, they were counted and recorded. All other material removed and collected from the sorghum panicles was examined using a dissecting microscope. Heliothine eggs and larvae found in both sorghum panicle collections in the laboratory and in cotton whole plant samples from the field were identified to species by using a compound microscope and

following the description of Neunzig (1969) of corn earworm and tobacco budworm eggs and larvae. All heliothine eggs were held for emergence of parasitoids or corn earworm first instars, which were reared to adults on a laboratory bean diet (Perkins et al. 1973) to ensure that the previous identifications of egg species were correct. All heliothine larvae also were held in diet cups for emergence of adult moths to determine that species were identified correctly. Voucher specimens of all insects are held in the USDA–ARS, Crop Protection and Management Research Laboratory in Tifton, GA.

Statistical Analysis. The sorghum and cotton trap crop plots were analyzed as a split, split-plot to obtain appropriate least squares means and standard errors associated with these means using PROC MIXED with Satterthwaite option (SAS Institute 1999). Fixed effects were treatment, date, and treatment \times date. Random effects were field, replicate (field), replicate \times treatment (field), planting date [sorghum only] \times section \times row \times sample number [sorghum only] \times plant number [sorghum only] (field \times replicate \times treatment), replicate \times date (field), and residual. Sample number was removed from the model for 2002 data because single plants were sampled. The field cotton plots were analyzed in a split, split plot to obtain appropriate least squares means and standard errors associated with these means using PROC MIXED with Satterthwaite option (SAS Institute 1999). Fixed effects were treatment, date, and treatment \times date. Random effects were field, replicate (field), replicate \times treatment (field), section \times length (field \times replicate \times treatment), replicate \times date (field), and residual. Control cotton was analyzed to obtain appropriate least squares means and standard errors associated with these means using PROC MIXED with Satterthwaite option (SAS Institute 1999). Fixed effects were date. Random effects were field, section \times length (field), date (field), and residual. Data were reduced to five dates for 2001 and seven dates for 2002 to use dates when corn earworm females were laying eggs. Corn earworm eggs per plant and percentage of plants with corn earworm eggs were adjusted for plant density for 2002 data. Arcsine transformation was applied to percentage data. Means for number of corn earworm eggs per plant, percentage of plants with corn earworm eggs, *O. insidiosus* per plant, and percentage of parasitization of corn earworm eggs by *T. pretiosum* from the trap crop plots, field cotton plots, and the control cotton fields were compared using Student's *t*-tests for unequal n-unequal variance. Number of corn earworm eggs collected from the sorghum panicles and sorghum plant population densities in sorghum trap crop plots were used to calculate mean abundances of corn earworm eggs in these plots converted to per hectare basis. Means for corn earworm eggs per plant and *O. insidiosus* per plant for both years were compared using Student's *t*-tests for unequal n-unequal variance.

In Georgia, the recommendation for control of heliothine larvae in 2001 was application of an insecticide when seven to eight small (≥ 0.6 cm in length) larvae

Table 1. Least squares means \pm SE (range) for no. corn earworm eggs per plant in sorghum trap crop plots, cotton trap crop plots, field cotton plots associated with sorghum trap crops, field cotton plots associated with cotton trap crops, and control cotton fields in 2001 and 2002

Treatment	2001		2002 ^a	
	<i>n</i>	Mean \pm SE (range)	<i>n</i>	Mean \pm SE (range)
Sorghum trap crop plots (1)	3,439	0.5336 \pm 0.0641 (0–28)	3,381	1.7899 \pm 0.2566 (0–18)
Cotton trap crop plots (2)	567	0.033 \pm 0.068 (0–2)	1,134	0.1014 \pm 0.2566 (0–3)
Field cotton plots next to sorghum trap crops (3)	1,009	0.0576 \pm 0.0188 (0–2)	1,082	0.0828 \pm 0.0273 (0–5)
Field cotton plots next to cotton trap crops (4)	972	0.0435 \pm 0.0188 (0–2)	1,090	0.0797 \pm 0.0273 (0–3)
Control cotton fields (5)	540	0.117 \pm 0.0154 (0–3)	635	0.1765 \pm 0.0185 (0–4)
Comparison of interest	df	<i>t</i>	df	<i>t</i>
1 vs. 2	11.5	5.36**	12.2	4.65**
3 vs. 4	10.3	0.53 NS	7.8	0.08 NS
1 vs. 3	11.5	7.13**	12.2	6.61**
2 vs. 4	11.5	–0.15 NS	12.2	0.08 NS
5 vs. (2, 3, 4)	137.1	1.61 NS	140.8	0.59 NS

Corn earworm eggs per plant significantly greater at ***P* < 0.01 (Student's *t*-test).
^a Adjusted for plant density.

per 100 plants were found before the first insecticide treatment, or five small larvae per 100 plants were found after the first insecticide spray (Brown et al. 2000). In this study, because all these fields had been sprayed earlier for control of the tobacco budworm, the economic threshold used for corn earworm was 5% infestation of young larvae (first and second instars) on cotton plants. The number of dates where the level of young corn earworm larvae exceeded an economic threshold of 5% was compared between the cotton in fields with trap crop plots and cotton in control fields without trap crop plots using Student's *t*-tests for unequal n-unequal variance.

Results and Discussion

Sorghum was highly attractive to corn earworm females and thus was preferred over cotton as an ovipositional site. The number of corn earworm eggs per plant and the percentage of plants with corn earworm eggs was significantly greater in the sorghum trap crop plots than in the cotton trap crop plots for both years (Tables 1 and 2). Also, a greater number of corn earworm eggs were oviposited on sorghum

panicles than on cotton plants in field cotton plots associated with the sorghum trap crop plots, and percentage of plants infested with corn earworm eggs was higher in sorghum trap than in field cotton next to this sorghum trap (Tables 1 and 2). Even cotton in the trap crop plots abutting corn was not attractive to corn earworm females, for no significant difference was detected in percentage of corn earworm egg infestation for cotton in these trap crops compared with cotton in field plots associated with these traps.

The mean number of corn earworm eggs per hectare on sorghum panicles in 2001 and 2002 was 163,669 \pm 262,174 and 383,543 \pm 206,124, respectively. These corn earworm egg densities were similar to the estimated numbers of corn earworm eggs per hectare recovered by Teetes et al. (1992) from sorghum panicles (same variety as used in our test) for two seasons, but lower for one season. The mean numbers of corn earworm eggs per panicle for both years of this test generally were lower than the numbers reported by Kring et al. (1989) in Arkansas because these researchers reported only data from flowering panicles, whereas we included data from all developmental stages of the sorghum.

Table 2. Least squares means (\pm SE) for percentage of plants with corn earworm eggs in sorghum trap crop plots, cotton trap crop plots, field cotton plots associated with sorghum trap crops, field cotton plots associated with cotton trap crops and control cotton fields in 2001 and 2002

Variable/Treatment/Comparison	2001		2002 ^a	
	<i>n</i>	Mean \pm SE	<i>n</i>	Mean \pm SE
Sorghum trap crop plots (1)	3,439	30.8 \pm 2.59	3,381	55.63 \pm 3.16
Cotton trap crop plots (2)	567	3.11 \pm 2.76	1,134	9.0 \pm 3.16
Field cotton plots next to sorghum trap crops (3)	1,009	5.42 \pm 1.43	1,082	6.87 \pm 2.01
Field cotton plots next to cotton trap crops (4)	972	3.78 \pm 1.43	1,090	7.14 \pm 2.01
Control cotton fields (5)	540	11.18 \pm 1.40	635	14.27 \pm 0.52
Comparison of interest	df	<i>t</i>	df	<i>t</i>
1 vs. 2	11.5	7.32**	10.6	10.45**
3 vs. 4	10.3	0.81 NS	8.0	–0.09 NS
1 vs. 3	11.5	8.58**	10.6	13.03**
2 vs. 4	11.5	–0.22 NS	10.6	0.50 NS
5 vs. (2–4)	136.8	2.92**	139.6	2.63*

Percentage of plants with corn earworm eggs significantly greater at ***P* < 0.01 or **P* < 0.05 (Student's *t*-test).
^a Adjusted for plant density.

Regardless of the cotton treatment, the number of corn earworm eggs on each plant was not only similar but also was within the expected range for this crop. There was no significant difference in the number of corn earworm eggs per plant between cotton in field plots associated with sorghum trap crop plots and cotton in field plots next to the cotton traps (Table 1). Also, the number of corn earworm eggs per plant was not significantly different between cotton in control fields and cotton in fields with trap crop plots (Table 1). When corn earworm eggs were present on plants, the number of eggs per plant ranged from one to four in 2001 and from one to five in 2002. Females oviposit a variable number of eggs, from an average of 1.4–2.1 on leaves and 1.67–2.32 on fruit, per oviposition visit (Wilson et al. 1980). The means and ranges of corn earworm eggs per plant in cotton in our study indicate that generally a single female laid eggs on a plant in cotton treatment plots.

Because grain sorghum was very attractive to corn earworm females, did strips of this plant species encourage movement of corn earworm females into the cotton field? No significant difference in the number of corn earworm eggs per plant and percentage of corn earworm infestation of plants occurred between field cotton associated with the sorghum trap crop plots and field cotton associated with the cotton trap crop plots (Tables 1 and 2). In addition, the percentage of corn earworm eggs per plant was significantly greater in the cotton fields without the sorghum trap crops compared with those with these trap crops for both years of the study (Table 2). These results indicate that the attractiveness of the grain sorghum to corn earworm females did not increase corn earworm activity in the cotton fields in this study.

Positioning the sorghum trap crop plots along the edge of the cotton field adjacent to corn apparently contributed to the success of the trap crops in trapping corn earworm. Lincoln and Isely (1947) found that silking corn seemed to be effective in attracting corn earworm females away from cotton, but if scattered stalks or single rows of corn were planted in cotton fields, corn earworm females were attracted and oviposited eggs not only on corn but also on nearby cotton plants. Robinson et al. (1972a, b) determined that cotton interplanted with grain sorghum exhibited greater square damage than cotton in control plots. Because their objective was to use intercropping to enhance natural enemies, the plots in their experiments were small, but the grain sorghum in these small plots may have attracted corn earworm females into the cotton. Parajulee and Slosser (1999) reported that there was no significant difference in the number of corn earworm larvae in cotton plots adjacent to grain sorghum compared with those adjacent to cotton checks. Again, plot size in their experiments was purposely small to encouraged movement of predators from grain sorghum into cotton, but the highly mobile corn earworm females may have oviposited equally on all host plants.

The main advantage of using trap crop strategies is that they can be highly effective at preventing pests

Table 3. Mean (\pm SE) no. dates exceeding an economic threshold of 5% young corn earworm larvae in control cotton fields and cotton fields associated with trap crop plots in 2001 and 2002

Year	Control cotton fields (1)			Cotton fields with trap crops (2)		1 vs. 2	
	<i>n</i>	Mean \pm SE		<i>n</i>	Mean \pm SE	df	<i>t</i>
2001	35	0.1429 \pm 0.06		47	0.0213 \pm 0.213	80	2.12*
2002	46	0.1957 \pm 0.0591		51	0.0588 \pm 0.0333	95	2.07*

Dates exceeding economic threshold significantly greater at * $P < 0.05$ (Student's *t*-test).

from entering cropping systems. In this study, corn earworm exhibited a strong ovipositional preference for grain sorghum over cotton, and so grain sorghum can serve as an effective trap crop for the corn earworm in cotton. In addition, higher corn earworm oviposition in cotton fields without sorghum trap crops compared with cotton with these trap crops indicates that these trap crops were not the source of corn earworm. Preliminary data using rubidium to mark corn earworm in corn suggests that this crop is the source of corn earworm eggs in cotton (P.G.T., unpublished data).

Stink bugs have emerged as pests of increasing importance in cotton (Williams 2003). Researchers have recognized that stink bugs can devastate bolls in edges of cotton when they disperse from other crops into cotton and have suggested that trap cropping could be a good approach for control of these pests (S. G. Turnipseed, personal communication). In 2002 and 2003, Southern green stink bugs were trapped in the grain sorghum trap crop plots (P.G.T., unpublished data). Since stink bugs can devastate bolls in edges of cotton when they disperse from other crops into cotton (P.G.T., unpublished data), trap cropping could be a good approach for control of these pests. In an on-farm research project conducted in 2002 and 2003, Southern green stink bugs were trapped in the grain sorghum trap crop plots (P.G.T., unpublished data). Several conventional cotton producers in the southeastern United States are interested in using this management strategy to help them prevent corn earworm and southern green stink bugs from entering their cotton fields. This trap crop also may provide a nonchemical control strategy for organic production of cotton.

Trap crops can not only be highly effective at trapping pests in cropping systems but they also offer the potential to minimize or eliminate the use of insecticides and preserve natural enemies that control pests. The mean number of dates with a level of corn earworms above the economic threshold of 5% young (first and second instars) larvae was higher for cotton in control fields compared with cotton in fields with trap crops for both these years (Table 3). Thus, the differences in percentage of corn earworm eggs infestation that occurred between cotton fields with and without trap crop plots were reflected in the number of times economic threshold was exceeded. For two cotton-growing seasons, the sorghum trap crop plots

Table 4. Least squares means \pm SE (range) for no. *O. insidiosus* per plant in sorghum trap crop plots, cotton trap crop plots, field cotton plots associated with sorghum trap crops, field cotton plots associated with cotton trap crops, and control cotton fields in 2001 and 2002

Treatment	2001		2002a	
	n	Mean \pm SE (range)	n	Mean \pm SE (range)
Sorghum trap crop plots (1)	3,439	0.7183 \pm 0.0832 (0–16)	3,381	1.6700 \pm 0.3036 (0–19)
Cotton trap crop plots (2)	567	0.0782 \pm 0.0873 (0–2)	1,134	0.2213 \pm 0.3036 (0–5)
Field cotton plots next to sorghum trap crops (3)	1,009	0.1692 \pm 0.0412 (0–4)	1,082	0.0742 \pm 0.0282 (0–3)
Field cotton plots next to cotton trap crops (4)	972	0.1376 \pm 0.0412 (0–3)	1,090	0.0603 \pm 0.0282 (0–4)
Control cotton fields (5)	540	0.3816 \pm 0.0329 (0–4)	635	0.211 \pm 0.0083 (0–5)
Comparison of interest	df	t	df	t
1 vs. 2	11.8	5.31**	13.4	3.37**
3 vs. 4	12.5	0.54 NS	10.1	0.35 NS
1 vs. 3	12.5	5.91**	13.4	5.23**
2 vs. 4	12.5	–0.62 NS	13.4	0.53 NS
5 vs. (2, 3, 4)	141.8	3.67**	146.6	0.52 NS

Percentage of plants with corn earworm eggs significantly greater at ** $P < 0.01$ (Student's t -test).

reduced the necessity for insecticide applications for this pest in cotton fields with these trap crops. Fewer insecticide inputs can increase profits for the grower and also preserve natural enemies that control pests. The possibility exists that an insecticide application in cotton for corn earworm may be unavoidable if the carrying capacity for the corn earworm is exceeded in the grain sorghum. However, the amount of insecticides and number of times applications are needed for control of corn earworm should be lower than that which would be needed for control of these pests in cotton fields without the trap crops, and natural enemies can be preserved in the trap crops.

One disadvantage of using grain sorghum as a trap crop for pest control is that land normally under cotton production has to be used for growing the trap crop. The trap crops, however, should help reduce the cost of cotton production by reducing pesticide inputs. Grain sorghum trap crops also can be profitable in other ways. Seed can be sold as food for wildlife or forage can be sold as food for cattle. The potential for growing grain sorghum organically in this management system is very high, and organic grain sorghum could be sold as organic chicken feed. The grain sorghum also could be managed as a wildlife refuge for birds.

The predator *O. insidiosus* was very prevalent in sorghum. Even though we did not obtain rates of predation of corn earworm eggs and larvae by *O. insidiosus*, the predator was observed on several occasions feeding on these immature stages of corn earworm. Occurrence of *Orius* spp. in grain sorghum has been reported previously (Fye and Carranza 1972, Lopez and Teetes 1976, Teetes et al. 1992). In our study, the mean number of *O. insidiosus* per sorghum panicle (Table 4) was higher than that reported for *Orius tristicolor* (White), 0.19 per panicle (Krauter et al. 1998) and 0.44 per panicle (Prasifka et al. 1999). For both years of our study, the number of *O. insidiosus* (nymphs and adults) per plant was significantly greater in sorghum trap crop plots than in cotton trap crop plots and cotton field plots associated with the sorghum (Table 4). Our findings are in agreement with those of Krauter et al. (1998) and Prasifka et al. (1999), who observed higher numbers of predators, including *O. tristicolor*, in sorghum panicles in the half-bloom stage than in cotton at this time in phenology of the grass.

Rates of parasitization of corn earworm eggs by *T. pretiosum*, the only parasitoid recovered from eggs in our study, were generally low in sorghum (Table 5). Nevertheless, egg parasitism rates in sorghum were

Table 5. Least squares means (\pm SE) for percentage parasitization of corn earworm eggs by *T. pretiosum* in sorghum trap crop plots, cotton trap crop plots, field cotton plots associated with sorghum trap crops, field cotton plots associated with cotton trap crops, and control cotton fields in 2001 and 2002

Treatment	2001		2002 ^a	
	n	Mean \pm SE	n	Mean \pm SE
Sorghum trap crop plots (1)	1,724	20.02 \pm 3.16	1,782	30.62 \pm 4.81
Cotton trap crop plots (2)	257	10.80 \pm 3.45	102	9.12 \pm 6.03
Field cotton plots next to sorghum trap crops (3)	250	10.75 \pm 1.68	79	27.34 \pm 3.62
Field cotton plots next to cotton trap crops (4)	233	8.52 \pm 1.73	79	36.79 \pm 3.62
Control cotton fields (5)	61	14.78 \pm 3.45	90	22.86 \pm 4.32
Comparison of interest	df	t	df	t
1 vs. 2	21.5	1.97 ⁺	14	2.79*
3 vs. 4	84.5	0.92 NS	114	–1.85 NS
1 vs. 3	84.5	2.59*	114	0.54 NS
2 vs. 4	84.5	0.59 NS	114	–3.93**
5 vs. (2–4)	236.5	1.13 NS	313.5	–0.25 NS

Percentage of plants with corn earworm eggs significantly greater at ** $P < 0.01$ or * $P < 0.05$ or ⁺ $P < 0.1$ (Student's t -test).

similar to those reported from other studies (Michael 1973, Puterka et al. 1985, Teetes et al. 1992). Depending on the sampling period, rates of egg parasitization in this study were similar to, higher than, or lower than those reported by Steward et al. (1990). Except for the equal parasitism by *Trichogramma* spp. and *Telenomus* spp. reported by Puterka et al. (1985), *Trichogramma* species were the predominant egg parasites of corn earworm eggs in grain sorghum in previous studies. In our study, rates of corn earworm parasitization were significantly higher in sorghum trap crop plots than in cotton trap crop plots for each year (Table 5). Puterka et al. (1985) also reported higher corn earworm egg parasitism in sorghum over cotton.

In addition to using a plant species highly attractive to the pest, a trap crop needs to be a sink for the pest species, or the pest has to be eliminated through crop destruction or application of insecticides. Most mobile pests are major pests. This may be largely because natural enemies of mobile pests have difficulty in shifting their habitats to follow the seasonal movement of the pests. The problem of dispersal by mobile natural enemies can be mitigated by incorporating a trap crop to make accessible the basic resources, including hosts/prey, of the natural enemies in relatively close temporal and spatial association to the agroecosystem. Localized aggregation of pests can lead to an enhanced numerical and functional response of their natural enemies. The higher number of *O. insidiosus* and higher rates of parasitization by *T. pretiosum* in sorghum trap crops compared with cotton trap crops seems to be a density response of these natural enemies to corn earworm density in sorghum. Hopper et al. (1991) suggested that increase in parasitism by *Microplitis croceipes* (Cresson) with host density resulted from the aggregation of females in cotton plots with high host density. Under this scenario natural enemies in trap crops may be able to prevent pest populations from increasing and dispersing to the main crop.

Life table studies for corn earworm in grain sorghum trap crop plots for the 2 yr of our study will be reported in a separate article. However, in a previous report, total real mortality (r_x) of the corn earworm in sorghum was shown to be very high (99%) (Tillman and Ruberson 2001). There was no significant difference between the mean number of corn earworm eggs and *O. insidiosus* per plant for both years of the tests (2001: $t = 1.76$, $P > 0.05$; 2002: $t = 0.03$, $P > 0.05$), suggesting that the ratio of corn earworm eggs to *O. insidiosus* was $\approx 1:1$ in sorghum panicles for both years. The mean number of corn earworm eggs eaten by *O. insidiosus* nymphs, males, and females per day in corn has been reported to be 1.43, 1.08, and 1.75, respectively (Barber 1936). Thus, it is not inconceivable that aggregation of this predator in these sorghum plots could maintain corn earworm eggs at very low levels. In Australia, scientists have been actively promoting trap crops as part of an areawide management strategy, and sorghum has been shown to have potential as a mid and late season sink for *Helicoverpa armigera* (Hübner) (Miles and Ferguson 2001). Teetes et al.

(1992) determined that real mortality for corn earworm was $>98\%$ by the end of the last larval stage for the open-panicle sorghum variety we used in our study indicating that this sorghum is a sink for CEW. In their study, disappearance of eggs was the major mortality factor for four of the six corn earworm populations studied, and it was speculated that predation could have accounted for some level of disappearance, but predators were not quantified. In our study, *O. insidiosus* was a prevalent predator in grain sorghum and was observed feeding on corn earworm eggs and young larvae in the field.

In 2001, the number of *O. insidiosus* was significantly lower in cotton in fields with trap crops compared with cotton in control fields. Congregation of the predator in sorghum where most of its prey was located probably accounted for these observed differences. However, sorghum was not a sink for *O. insidiosus*; for the predator also was found in field cotton plots associated with both sorghum and cotton trap crops. Additionally, preliminary data using rubidium to mark *O. insidiosus* indicates that this predator moves from corn into cotton field plots associated with trap crop plots (P.G.T., unpublished data). Predation of corn earworm eggs by this predator in concert with other cotton insect predators probably was not adversely effected by the lower levels of this predator in cotton fields with trap crop plots because economic threshold was reached on fewer dates in cotton fields with trap crops than in control cotton fields. In 2002, there was no significant difference in number of *O. insidiosus* in cotton in fields with trap crops compared with cotton in control fields, suggesting again that sorghum was not a sink for this predator.

The presence of grain sorghum near cotton can enhance predator abundance in cotton. Fye (1971) described a system in which populations of insect predators increased in grain sorghum and dispersed into cotton as the former crop matured. Fye and Caranza (1972) determined that the predators move an appreciable distance (160 m) from grain sorghum into cotton, and thus the interplanting of grain sorghum and cotton to promote predators in cotton need not be restricted to alternate plantings of small numbers of rows. Lopez and Teetes (1976) reported that predator population levels in cotton began to increase at the same time that predator density began to decrease in sorghum. Of the many predators captured, marked with a pigment, and released in grain sorghum, 0.01% was captured in nearby cotton demonstrating that predators did move from grain sorghum into cotton. Predator abundance was significantly higher in cotton adjacent to a spring relay-strip crops of sorghum for the first half of the cotton season (Parajulee and Slosser 1999). Using fluorescent dust markers, Prasifka et al. (1999) demonstrated that predators move between cotton and sorghum in both directions, and sorghum can contribute predators to cotton. The most likely explanation for the apparent lack of enhancement of predators in cotton field plots with grain sorghum trap crops in this study is that attractive panicles of sorghum were continuously available in

the trap crop plots whereas in other studies the predators were encouraged to leave sorghum as this crop began to senesce.

Rates of corn earworm parasitization were not significantly different between cotton fields with trap crops and control cotton fields (Table 5). The similarity in rates of heliothine egg parasitization in control cotton fields and cotton fields with trap crops suggests that the sorghum trap crop was not a sink for *T. pretiosum*, even though rates of parasitization were generally higher in sorghum than in cotton. Again, an enhancement of *T. pretiosum* in cotton may not have occurred because of the continual attractiveness of the grain sorghum.

In summary, using grain sorghum to the corn earworm can be very effective in cotton fields. This pest management strategy can reduce the need for insecticide applications for this pest increasing on-farm sustainability by reducing production costs and conserving natural enemies of pests in cotton.

Acknowledgments

We thank John D. Pinto for identifying the trichogrammatid we collected during this investigation. We also thank Penny Tapp and Kristie Graham for technical assistance. We thank the Georgia Cotton Commission and Cotton Incorporated for financial support of this research.

References Cited

- Adameczyk, J. J., Jr., D. D. Hardee, L. C. Adams, and D. V. Summerford. 2001. Correlating differences in larval survival and development of bollworm (Lepidoptera: Noctuidae) and fall armyworm (Lepidoptera: Noctuidae) to differential expression of Cry1A(c) δ -endotoxin in various plant parts among commercial cultivars of transgenic *Bacillus thuringiensis* cotton. *J. Econ. Entomol.* 94: 284–290.
- Barber, G. W. 1936. *Orius insidiosus* (Say), an important natural enemy of the corn earworm. U.S. Dep. Agric. Tech. Bull. 504.
- Barber, G. W. 1937. Seasonal availability of food plants of two species of *Heliothis* in eastern Georgia. *J. Econ. Entomol.* 30: 150–158.
- Box, G.E.P., W. G. Hunter, and J. S. Hunter. 1978. Statistics for experiments, an introduction to design, data analysis, and model building. Wiley, New York.
- Brown, S. M., M. Bader, S. Culpepper, R. Davis, G. Harris, B. Kemerait, P. Roberts, and D. Shurley. 2000. 2001 Georgia cotton production guide. Cooperative Extension Service, University of Georgia, Athens, GA.
- Deming, W. E. 1950. Some theory of sampling. Dover Publications, Inc., New York.
- Graham, H. M., N. S. Hernandez, Jr., and J. R. Llanes. 1972. The role of host plants in the dynamics of populations of *Heliothis* spp. *Environ. Entomol.* 1: 424–431.
- Fye, R. E. 1971. Grain sorghum: a source of insect predation for insects on cotton. *Prog. Agric. Ariz.* 23: 12–13.
- Fye, R. E., and R. L. Carranza. 1972. Movement of insect predators from grain sorghum to cotton. *Environ. Entomol.* 6: 790–791.
- Hokkanen, H.M.T. 1991. Trap cropping in pest management. *Annu. Rev. Entomol.* 36: 119–138.
- Hopper, K. R., J. E. Powell, and E. G. King. 1991. Spatial density dependence in parasitism of *Heliothis virescens* (Lepidoptera: Noctuidae) by *Microplitis croceipes* (Hymenoptera: Braconidae) in the field. *Environ. Entomol.* 20: 292–302.
- Krauter, P.C., K. M. Heinz, C. G. Sansone, and A. England. 1998. Contributions of grain sorghum to natural enemy populations in cotton, pp. 1102–1105. *In* Proceedings, Beltwide Cotton Conferences. National Cotton Council, Nashville, TN.
- Kring, T. J., W. C. Yearian, and V. B. Steward. 1989. Within-field and within-panicle distribution of *Heliothis zea* (Lepidoptera: Noctuidae) and *Celama sorghiella* (Lepidoptera: Noctuidae) eggs in grain sorghum. *Environ. Entomol.* 18: 150–156.
- Lincoln, C., and D. Isely. 1947. Corn as a trap crop for the cotton bollworm. *J. Econ. Entomol.* 40: 437–438.
- Lopez, E. G., and G. L. Teetes. 1976. Selected predators of aphids in grain sorghum and their relation to cotton. *J. Econ. Entomol.* 69: 198–204.
- Merchant, M. E. 1989. Practical sampling procedure for panicle-infesting insect pests of sorghum. Ph.D. dissertation, Texas A&M University, College Station, TX.
- Michael, P. J. 1973. Biological control of *Heliothis* in sorghum. *J. Agric. West. Aust.* 14: 222–224.
- Miles, M., and J. Ferguson. 2001. Trap-cropping: a fad or a useful *Heliothis* management tool. (www.dpi.qld.gov.au/fieldcrops/6976.html).
- Neunzig, H. H. 1969. The biology of the tobacco budworm and the corn earworm in North Carolina. North Carolina State University, Agricultural Experiment Station Tech. Bull. 196.
- Parajulee, M. N., and J. E. Slosser. 1999. Evaluation of potential relay strip crops for predator enhancement in Texas cotton. *Int. J. Pest Manage.* 45: 275–286.
- Parsons, F. S. 1940. Investigations on the cotton bollworm, *Heliothis armigera*, Hübner. Part III. Relationships between oviposition and the flowering curves of food-plants. *Bull. Entomol. Res.* 31: 147–177.
- Perkins, W. D., R. L. Jones, A. N. Sparks, B. R. Wiseman, J. W. Snow, and W. W. McMillan. 1973. Artificial diets for mass rearing the corn earworm (*Heliothis zea*). USDA-ARS, Production Research Report No. 154.
- Prasifka, J. R., K. M. Heinz, and P. C. Krauter. 1999. Natural enemy movement between adjacent sorghum and cotton fields, pp. 1112–1114. *In* P. Dugger and D. Richter [eds.], Proceedings, Beltwide Cotton Conferences. National Cotton Council, Nashville, TN.
- Puterka, G. J., J. E. Slosser, and J. R. Price. 1985. Parasites of *Heliothis* spp. (Lepidoptera: Noctuidae): parasitism and seasonal occurrence for host crops in the Texas Rolling Plains. *Environ. Entomol.* 14: 441–446.
- Quaintance, A. L., and C. T. Brues. 1905. The cotton bollworm. USDA Bureau Entomol. Bull. 50: 1–155.
- Ridgway, R. L. 1969. Control of the bollworm and tobacco budworm through conservation and augmentation in predaceous insects. *Proc. Tall Timbers Conf. Ecol. Anim. Control Habitat Manage.* 1: 127–144.
- Robinson, R. R., J. H. Young, and R. D. Morrison. 1972a. Strip-cropping effects on abundance of *Heliothis*-damage cotton squares, boll placement, total bolls, and yields in Oklahoma. *Environ. Entomol.* 1: 140–145.
- Robinson, R. R., J. H. Young, and R. D. Morrison. 1972b. Strip-cropping effects on abundance of predatory and harmful cotton insects in Oklahoma. *Environ. Entomol.* 1: 145–149.
- Roome, R. E. 1975. Activity of adult *Heliothis armigera* (Hb) (Lepidoptera: Noctuidae) with reference to the flower-

- ing of sorghum and maize in Botswana. *Bull. Entomol. Res.* 65: 523–530.
- SAS Institute. 1999. SAS/STAT user's guide, version 8. SAS Institute, Cary, NC.
- Sevacherian, W., and V. M. Stern. 1974. Host plant preferences of *Lygus* bugs in alfalfa-interplanted cotton fields. *Environ. Entomol.* 3: 761–766.
- Snow, J. W. 1964. Seasonal occurrence of tobacco budworm on cotton in Georgia. *J. Econ. Entomol.* 57: 787–788.
- Stern, V. M., A. Mueller, V. Sevacherian, and M. Way. 1969. *Lygus* bug control in cotton through alfalfa interplanting. *Calif. Agric.* 23: 8–10.
- Steward, V. B., W. C. Yearian, and T. J. Kring. 1990. Parasitism of *Heliothis zea* (Lepidoptera: Noctuidae) eggs and larvae and *Celama sorghiella* (Lepidoptera: Noctuidae) eggs on grain sorghum panicles. *Environ. Entomol.* 18: 150–156.
- Stinner, R. E., R. L. Rabb, and J. R. Bradley. 1977. Natural factors operating in the population dynamics of *Heliothis zea* in North Carolina, pp. 622–642. *In* Proceedings, 15th International Congress of Entomology, Washington, DC.
- Teetes, G. L., M. J. Scully, and G. C. Peterson. 1992. Partial life tables for corn earworm (Lepidoptera: Noctuidae) on compact- and loose-panicle sorghum hybrids. *J. Econ. Entomol.* 85: 1393–1401.
- Tillman, P. G. 1995. Susceptibility of *Microplitis croceipes* and *Cardiochiles nigriceps* (Hymenoptera: Braconidae) to field rates of selected cotton insecticides. *J. Entomol. Sci.* 30: 390–396.
- Tillman, P. G., and J. E. Mulrooney. 2000. Effect of selected insecticides on the natural enemies, *Coleomegilla maculata* and *Hippodamia convergens* (Coleoptera: Coccinellidae), *Geocoris punctipes* (Hemiptera: Lygaeidae), and *Bracon mellitor*, *Cardiochiles nigriceps*, and *Cotesia marginiventris* (Hymenoptera: Braconidae) in cotton. *J. Econ. Entomol.* 93: 1638–1643.
- Tillman, P. G., and J. R. Ruberson. 2001. Grain sorghum as a trap crop for the corn earworm in cotton, pp. 1158–1159. *In* D. D. Hardee and E. Burris [eds.], Proceedings, Beltwide Cotton Conferences. National Cotton Council, Nashville, TN.
- Tillman, P. G., and W. Scott. 1997. Susceptibility of *Cotesia marginiventris* (Cresson) (Hymenoptera: Braconidae) to field rates of selected cotton insecticides. *J. Entomol. Sci.* 32: 303–310.
- Vanderlip, R. L. 1972. How a sorghum plant develops. *Kans. Agric. Exp. Sta. Dep. Agron.* 1203.
- Willers, J. L., S. R. Yatham, M. R. Williams, and D. C. Akins. 1992. Utilization of the line-intercept method to estimate the coverage, density, and average length of row skips in cotton and other row crops, pp. 48–59. *In* Proceedings, Kansas State University Conference on Applied Statistics in Agriculture. Kansas State University, Manhattan, KS.
- Williams, M. R. 2003. Cotton insect losses –2002, pp. 1217–1273. *In* D. D. Hardee, R. S. Ottens, G. Burris, and J. A. Ottea [eds.], Proceedings, Beltwide Cotton Conferences, 6–10 January 2003, Nashville, TN. National Cotton Council, Memphis, TN.
- Wilson, L. T., A. P. Gutierrez, and T. F. Leigh. 1980. Within-plant distribution of the immatures of *Heliothis zea* (Boddie) on cotton. *Hilgardia* 48: 12–23.

Received 9 September 2003; accepted 9 June 2004.